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Measurements of Higgs boson spin-parity properties and study of the tensor structure in the $H \to VV$ vertex with Run-1 collected data at ATLAS experiment at LHC

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Summary. — The measurement of spin and parity of the Higgs boson in $H \to ZZ^* \to 4\ell$, $H \to WW^* \to e\nu\mu\nu$ and $H \to \gamma\gamma$ channels performed by the ATLAS experiment is presented. The tensor structure of the $H \to VV$ interaction in the spin-0 sector is also reported. The full dataset recorded during the Run 1 has been used, corresponding to an integrated luminosity of $\sim 25\,\text{fb}^{-1}$.

1. – Theoretical models

After the discovery of a new Higgs-like boson by ATLAS [1] and CMS [2] experiments at LHC, a major goal is to establish the nature of this particle by determining its spin-CP properties, thus providing its compatibility with the Standard Model (SM) previsions. The Lagrangian which describes the interactions between the Higgs boson and the SM vector bosons adopts an effective field theory (EFT) approach, valid up to a certain scale of energy Λ, whose value is 1 TeV. The models tested refers to SM spin-0 and BSM spin-0 CP-even and CP-odd states with the following interaction Lagrangian:

$$\begin{aligned}(1)\qquad \mathcal{L}_0^V = \Bigg\{ & c_\alpha \kappa_{\text{SM}} \left[\frac{1}{2} g_{HZZ} Z_\mu Z^\mu + g_{HWW} W_\mu^+ W^{-\mu} \right] \\ & - \frac{1}{4}\frac{1}{\Lambda} \left[c_\alpha \kappa_{HZZ} Z_{\mu\nu} Z^{\mu\nu} + s_\alpha \kappa_{AZZ} Z_{\mu\nu} \tilde{Z}^{\mu\nu} \right] \\ & - \frac{1}{2}\frac{1}{\Lambda} \left[c_\alpha \kappa_{HWW} W_{\mu\nu}^+ W^{-\mu\nu} + s_\alpha \kappa_{AWW} W_{\mu\nu}^+ \tilde{W}^{-\mu\nu} \right] \Bigg\} X_0\end{aligned}$$

where κ_{SM}, κ_{HVV} and κ_{AVV} are, respectively, the coupling constants corresponding to the interaction of the SM, BSM CP-even or BSM CP-odd spin-0 particle, represented by the X_0 field, with ZZ or WW pairs. CP-mixed states and CP-violation occurr when $\alpha \neq 0$ and $\alpha \neq \pi$, where α is the mixing angle, c_α and s_α are respectively $\cos\alpha$ and $\sin\alpha$.

For the spin-2 hypothesis the interaction Lagrangian is parametrized by the couplings κ_V and κ_f. The scenario where all couplings have a same value is called Universal

TABLE I. – *Observed CL_s for the combination of the three channels for the fixed hypothesis test analysis. The transverse momenta are expressed in GeV.*

J^P	Obs. CL_S
0_h^+	$4.7 \cdot 10^{-2}$
0^-	$< 2.6 \cdot 10^{-2}$
2^+(UC)	$1.1 \cdot 10^{-2}$
$2^+(\kappa_q = 0;\ p_T < 300)$	$< 6.5 \cdot 10^{-3}$
$2^+(\kappa_q = 0;\ p_T < 125)$	$1.5 \cdot 10^{-2}$
$2^+(\kappa_q = 2\kappa_g\ p_T < 300)$	$< 4.3 \cdot 10^{-2}$
$2^+(\kappa_q = 2\kappa_g\ p_T < 125)$	$3.7 \cdot 10^{-2}$

TABLE II. – *Best-fit values and observed CL_s in the tensor structure analysis for the combination of $H \to ZZ^* \to 4\ell$ and $H \to WW^* \to e\nu\mu\nu$ channels.*

J^P	Best fit	Observed CL_S
$\tilde{\kappa}_{HVV}/\kappa_{\rm SM}$	-0.48	$(-\infty, -0.73] \bigcup [0.63, \infty)$
$\frac{\tilde{\kappa}_{AVV}}{\kappa_{\rm SM}} \cdot \tan\alpha$	-0.68	$(-\infty, -2.18] \bigcup [0.83, \infty)$

Coupling (UC), otherwise it is called non-UC. The QCD production of a spin-2 particle is driven by the values of the couplings $\kappa_g,\ \kappa_q$, where q refers to light quarks. With this parameterization UC scenario corresponds to the $\kappa_q = \kappa_g$ (UC) case. In this analysis a selection on Higgs p_T is applied for non-UC scenarios.

2. – Results

Two different methods for the study of spin-CP Higgs boson properties have been used: a fixed hypothesis test and a measurement of the tensor structure of the $H \to VV$ interaction.

For the fixed hypotheses studies, an analysis based on observables sensitive to the spin and parity of the signal has been used. The likelihood function constructed, $\mathcal{L}(\text{data} \mid J^P, \mu, \vec{\theta})$, depends on the spin-parity hypothesis J^P, the signal rate normalised to the SM prediction μ and nuisance parameters $\vec{\theta}$. The test statistics used is the ratio of profile likelihoods, and the exclusion of the alternative hypothesis J^P_{alt} in favour of the SM J^P_{SM} is expressed in terms of CL_s. The combined results show a preference of the $J^P = 0^+$ SM hypothesis compared to the alternative hypotheses (table I).

In the tensor structure analysis a spin-0 hypothesis has been assumed, and, together with SM contribution, positive and negative parity BSM contributions are considered. The possible BSM contributions, measured in $H \to ZZ^* \to 4\ell$ and $H \to WW^* \to e\nu\mu\nu$ channels are evaluated in terms of $(\tilde{\kappa}_{AVV}/\kappa_{\rm SM}) \cdot \tan\alpha$ and $\tilde{\kappa}_{HVV}/\kappa_{\rm SM}$ by using a fitting procedure. The combined results in table II are expressed at 95% CL.

Details on this analysis can be found at [3].

REFERENCES

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